STUDY OF THE CHANGES OF THE HEART'S SHADOW DURING SYSTOLE AND DIASTOLE AS SHOWN BY THE X-RAY

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Introduction

The lack of knowledge of the x-ray shadow changes of the heart during systole and diastole, and even a much less knowledge of the heart's actual output, has made this research problem a very interesting one, not only from a purely scientific standpoint but from a clinician's standpoint as well. The object of this paper is to set forth the results obtained of determining the volume changes of the heart by means of measuring the difference in shadow area of the heart during systole and diastole. This important problem has opened itself to attack by the recent research work of Dr. Bardeen whose exhaustive work upon this subject has thrown much light upon the question of volume as related to the heart shadow area. The shadow area obtained by actual x-ray work were compared to his standard table of shadow area and volume, and thus a working basis was created for the results obtained.

The problem undertaken was to determine the hearts actual output with the subject in both sitting and lying positions. As will be seen, however, not much data has been obtained in the latter position. As the amount of work done upon this subject has been very limited, the amount of available literature is correspondingly small. A brief resume' will be given of the most important work done

along this line both on man and on lower animals.

One of the earliest records that we have perhaps is that of Passawant (Stewart's Physiology '05, 5th ed. p. 113) who in the middle of the eighteenth century calculated the output to be 46.5 grams (42.75 cc.) which data, however, is generally conceded to be too low. Tigerstedt ('06 Murlin p. 178) states; "We cannot say as yet with definiteness how great is the quantity of blood expelled from the human heart at each systole. It is very probable that the pulse volume is somewhere between 50 and 100 grams per beat". Martin (Human Body '06 p. 235) on the other hand states that at each systole each ventricle sends out 180 grams.

Krogh and Lindhard (Skand. Archiv. f. Physio. 27, 100, 1912., Howell) in this research work by indirect means calculated the output of the right ventricle in man to be from 2.8 liters per minute during rest to 21.6 liters during muscular exercise. Changing this to cubic centimeters and assuming the heart rate to be normal (70), the variation would be from 40 cc. per beat during rest to 308.57 cc. per beat during muscular exercise. Krogh and Lindhard explain this wide variation by concluding that it is due to the variation in the venous filling of the heart during diastole. When a person is at rest the inflowing venous blood is insufficient to distend the heart completely, during muscular exercise, however, the increase in the venous pressure and the increased velocity distends the heart in its diastolic

phase as far as its musculature will allow.

According to Henderson (Amer. Jour. of Physiol. 16, 325 '06) the dogs output from the left ventricle when the heart beat is normal (90) is approximately .002 of the body weight.

Stolnikow (Arch. f. Physiol. Leipzig 1886, S. 1., Schaeffer) attempted to measure the outflow by tying all the aortic branches except the axillary, from which vessel he collected the blood. He then sent the blood back to the heart by way of the external jugular vein. By means of this experiment he found the output to be .00032 to .00016 of the body weight.

Tigerstedt (Skandin. Archiv. f. Physiol. Leipzig 1892-93, Bd. iii S. 145., Schaeffer) in measuring the flow of blood by means of a stromuhr, in the aorta of a rabbit found the mean outflow was .00027 of the body weight and the output per second .00085 of the body weight.

Zuntz, (Deutsche Med. Wochenschr., Leipzig 1892, S.109., Schaeffer) used an indirect method for determining the output, based on a comparison of the difference in gases contained between arterial and venous blood, and the actual amount of O_2 taken from the air into the lungs. By this method he calculated the output of the right ventricle of the horse in one minute to be equivalent to .00122 of the body weight per second. Using this same method on a dog, Zuntz found the output to be .00157 of the body weight. From these results

he calculated the output of man to be approximately 60 cc., this however, according to Zuntz may be doubled during exercise.

Zuntz and Tigerstedt's results show some correlation (Schaeffer 1900 Vol. II p. 49).

.00085	of body	wt.	(maximal	.00132)	Rabbit.	Tigerstedt
.00122 "	"	"	"	"	Horse.	Zuntz
.00157 "	"	"	"	"	Dog.	Zuntz

Tigerstedt (Starling's Physiol.'12 p. 1026-1031) used the plethysmographic method for determining the output. He used the pericardial sac as the chamber of the plethysmograph. The pericardium was filled with oil as the oncometer and the changes in the volume of the heart was registered by connecting the cavity of the pericardium with a form of piston recorder. The objections which have been raised to the above method is that the pericardial sac is not rigid enough for using it as a plethysmograph; furthermore a distension of the pericardial sac impedes the normal diastole of the heart. The error due to these causes has been eliminated by using either a metal or glass plethysmograph, but as there is no basis for calibration, the results obtained are certainly not satisfactory. The plethysmographic method is, furthermore, limited to use only on lower animals.

Stewart (Starling's Physiol. '12 p. 1026-1030) determined the output by injecting a solution of methylene blue into the central end of the jugular vein. This was collected from the peripheral end of the same jugular vein 27 heart

beats after the injection. By dividing the quantity of blood in man (3000 gms. in a man of 60 kilos) by 27; so as to arrive at the output of each ventricle, he calculated each cardiac systole at about 111 grams or 102.08 cc. The objections to this method are that it represents perhaps the shortest possible time in which the blood can come back. It is not known where or how far it went, it may have taken the shortest cuts possible; in view of this fact the output of the left ventricle in man then must be considerably less.

Another method by which Stewart (Stewart's Physiol. 5th ed. '05 p. 113) estimated the output was by first measuring the amount of blood which passed through the heart in 1 minute; he found this to be 4½ kilos. Taking the average pulse rate as 72 per minute, the quantity ejected by either ventricle with every systole would be $\frac{4500}{72}$ or 62.5 grams or a little less than 60 cc. He also experimented on 20 dogs whose weights ranged from 5 to 35 kilos. Stewart showed that the output or contraction volume of the left ventricle per kilo of body weight diminished as the size of the animal increased. From the relation between output and body weight, he calculated that the output of a man weighing 70 kilos would be no more than 105 grams of blood per second or 87 grams (80 cc.) per heart beat with a normal pulse rate of 72. By comparing this result with the circulation time of the blood, he calculated the output of each ventricle to lie between 70 and 80 cc. at each beat.

Schaeffer (Schaeffer's Physiol. Vol. II 1900 p. 48-53) states that the systolic output can be measured by hydrodynamic formulae, after certain data are obtained by experimental measures. The output by this method was calculated to be 160 cc., but it is contended that this is far too high.

Volkmann (Die Hamodynamik, Leipzig, 1850, S. 204., Schaeffer) and Vierordt (Die Erscheinungen und Gesetze der Stromgeschwindigkeiten des Blutes, Frankfurt 1858, S. 104., Schaeffer) by estimating the velocity of the blood flow in the carotid artery and comparing this vessel to the sectional area of the aorta, calculated the rate of flow in the aorta and thus the output of the heart per second. The fallacy of this method as set forth by Schaeffer is that the flow in the carotid artery depends upon the proportionate relation which exists between the carotid vascular area and the remainder of the arterial system. He contends, therefore, that this method cannot be considered accurate.

Vierordt (Anat. Physiol. und Physik. daten und tabällen. 1893 p. 61) gives some interesting figures on heart volume which are as follows:

Age	Weight	Ventricular output
Newborn	3.2 kilos	9.06 cc.
3 years	12.5 "	35.4 "
14 years	34.4 "	97.4 "
Adult	63.6 "	180 "

Lastly, we shall consider Lindhart's results (Lindhart, Ueben des Minutenvolume des Herzens bei Ruhe und bei Muskelarbeit. Pflügers. Archiv. Vol. 166, 1915. p. 233-283). He states that the pulse volume varies from 88 cc. in rest to 208 cc. during exercise; this result, however, was based on one experiment, and it is thought that this increase is probably exceptional. In another experiment on a woman, Lindhart calculated the volume during rest as 50 cs. and during exercise as 77 cc. He has found that the pulse volume varies from day to day when one is not actively at exercise; the following tables show this:

Subject - male	
May 13,	66 cc.
May 15,	75 cc.
May 29,	75 cc.
Avg.	72 cc.

Subject - female:	
Oct. 4,	64 cc.
Oct. 7,	68.5 cc.
Oct.10,	76 cc.
Oct.19	78 cc.
Oct. 21	76 cc.
Oct. 27	86 cc.
Avg.	74.75 cc.

The question now arises as to the authenticity of these numerous results; on the whole they have shown a rather wide variation. No doubt but that some of the results agree rather closely, and considering the many different methods used, perhaps they correlate as well as can be expected. It must be conceded moreover, that much painstaking and careful

work has been done on this important subject; the fault seems to lie, however in the methods employed, that is, no accurate practical method has thus far been found. After considering a few of the important principles involved in measuring the output and changes in the area of the heart, the question of obtaining the heart's output by the measurement of its shadow area will be described.

We may first consider the relation of the thorax and abdomen to ventricular output. Schaeffer(Physiol. Vol. 2 1900 p. 52) states that if the thorax is compressed, the pulmonary circulation is obstructed and the filling of the left ventricle is not complete. If on the other hand, the abdomen is compressed, the filling of the right ventricle is aided and the output per second is increased. If too much blood, however, is returned to the heart the fact that the output is greatly increased, causes the blood pressure to rise, and the result is that it becomes so great that the heart cannot pump against this counter pressure. According to Schaeffer, if the heart attempts to enlarge its output it is at a disadvantage, for if the ventricle is enlarged to twice its diameter, approximately 8 times as much muscle force must be used to produce the same pressure. Thus, powerful compression of the abdomen dilates the right heart and at the same time opposes the emptying of the left ventricle. Mention is also made of the fact that if the heart musculature is weakened by $CHCl_3$ or by asphyxia, and if the abdomen is

then forcibly compressed, the right ventricle may be thrown into a condition of paralytic dilitation. Lindhart(Pflügers Archiv. 166, '15 pp. 233-283) discusses the question of minute pulse volume as related to exercise. The minute volume of the heart may rise during exercise six times over that at rest. The pulse volume of the heart is enlarged by muscular exercise, but since the minute volume may vary independent of pulse volume, no conclusions may be drawn about one for the other. The effect of exercise and training is to cause during rest an increase of metabolism and in relation to this a still greater increase in minute volume and a less complete use of the O_2 in the blood; the pulse frequency is also lessened, but there is a very marked increase of the pulse volume. During exercise the individual shows less relative increase in metabolism and minute volume; the oxygen is more completely used, there is a relatively lower pulse frequency and a smaller pulse volume.

The main principle of cardiac output is that it depends upon the diastolic filling of the heart; therefore, anything which causes a rise of venous pressore or which causes the blood to flow into the right auricle faster must needs give the heart a greater output - then too, a lengthened diastole will also give a greater output. In this connection, it may be assumed that the ventricles must have approximately the same output, otherwise we would have to think of the blood as being dammed back some place, and that there were reservoirs in certain tissues in the body to receive this

blood, the latter is quite inconceivable, as no evidence has even been found for this.

Tigerstedt (Schaeffer Vol. II,1900, p. 50) from his researches on the output of the heart concludes:

1. That within certain limits the systolic output is independent of the resistance.

2. That under favorable conditions a rise of resistance may increase the systolic output.

3. That with increasing peripheral resistance the systolic output as a rule decreases.

4. That as the arterial pressure generally increases in spite of the diminished systolic output, the diminution in output per second must be proportionately smaller than the increase in resistance.

Having now considered a few of the most important principles which influence the cardiac output and having reviewed the methods and results obtained by the most prominent workers, we may consider next the method used in obtaining the systolic output by means of the shadow area of the heart.

Methods and Description of the Machine.

In order to photograph the heart during systole and diastole, a special apparatus was designed by Dr. J. A. E. Eyster to be attached to the x-ray machine. Briefly, this machine was so constructed that the moment a weight was released, the heart was taken in systole; the weight then

passing through a known distance caused a switch to be thrown in, which completed the circuit and caused the heart to be taken in its diastolic period. The weight was set off automatically by the carotid wave, which was transmitted to a compound mercury tambour, and this tambour by making contact through the mercury be means of an electromagnet released the weight. In more detail this apparatus consisted of two brass perpendicular parallel bars approximately 160 centimeters in height and about 10 cm. apart; these bars were supported on a cast iron standard. A sliding weight was interposed between these bars and prevented from slipping out by flanged grooves. This sliding weight was held at the top of the bars by a small "catch" which could be automatically released by an electromagnet. A small switch which when thrown in set off the machine, was so arranged that it could be adjusted to any height on the parallel bars; this switch in turn was thrown in by the sliding weight. Knowing, therefore, the number of centimeters through which the weight fell, by the law of falling bodies, that is from a body at rest, the time could be calculated in which it took the weight to fall from the top of the bars where it was held by an electromagnet to the height at which the switch was set. The apparatus was further arranged, so that the instant the weight was released, the heart was taken in systole; when the weight struck the adjustable switch previously mentioned, the heart was taken in its diastolic phase. Thus, by running a trial experiment or two, the apparatus could be arranged so that the

heart could be taken at the height of systole and a little later in its greatest diastole. The period in which the heart was taken could be ascertained by noting its relation to the carotid wave tracing on the kymograph as will be explained later. Two fuses were in the electrical current, therefore the instant the first picture was taken, one fuse was blown out, this prevented the current from passing through this circuit again, the next instant the second fuse was blown out, the apparatus was in this way cut off from the x-ray machine.

In order to obtain the time relations it was of course necessary to record the instant the picture was taken. This was done by having two electric marking pens connected to the first and second switch respectively, the first marking pen making its scratch line on the kymograph when the first picture was taken and the second marking pen making its scratch line when the second picture was taken. On this same kymograph the carotid pulse was recorded and also the respiration, the latter being recorded by a special belt which was put around the subjects abdomen. The tube which conveyed the carotid pulse and also the tube which conveyed the respiratory movements were attached to their respective compound mercury tambours, which by making contact thru the mercury completed the circuit, thus releasing the sliding weight. A switch board was so arranged that the current was only completed during deep inspiration. The regularity of the pulse transmissions could be detected by watching a

small ammeter; when the hand of the latter registered a definite number of degrees at each heart beat, the kymograph was started and the small switch on the switch board, which caused the picture to be taken only in deep inspiration, was thrown in, the tambour then completing the circuit through the mercury cups, set off the electromagnet, which in turn released the sliding weight and as before described a picture was taken in systole and one in diastole. To summarize- A typical record showed the first marking pen making its scratch line which coincided approximately with the height of systole of the carotid tracing, while the second marking pen made its scratch line at a point corresponding to the diastole in the carotid curve. As these followed each other so rapidly, they of course both took place during inspiration. A tuning fork which vibrated 100 times per minute was used to ascertain the time relations between systole and diastole, the time which elapsed between the taking of the two pictures generally averaged about 25 hundreths of a minute.

The subject each time was put at the same distance from the x-ray tube, that distance being two meters, in the lying as well as in the sitting position. As soon as the pictures were taken the subject's systolic and diastolic pressure was taken as was also the pulse rate. There were put on the kymograph record and were used later for means of correlation as will be explained.

The pictures were taken on a film size 14 x 17; it was

necessary to use intensifying screens as the time of exposure was very short. The films were developed immediately in fresh developer and left in the developing solution about 15 minutes. After they were cleared up in the hypo bath and washed, a satisfactory negative showed two distinct outlines of the heart, the diastolic shadow superimposed upon the systolic shadow. The differences in area were then measured by means of the planimeter.

Results

We may now consider the results obtained by measuring the differences in the two shadow areas. By using the tables compiled by Dr. Bardeen the correct volume which corresponded to that area was looked up. By finding the difference in area between systole and diastole and dividing the result by the diastolic area, the comparative area in percent was found, or the percentage of decrease of diastolic area during systole. This was also done with the volume; then the percentage of decrease of diastolic volume during systole was found. These percentages were added from 19 subjects and the average for the area was 12.47%; that of the volume was 18.736%.

These percentages were then used and the subjects were arranged according to weight; a variation of five pounds was allowed. The following table shows the result:

Percentage of decrease of diastolic area and volume during systole in relation to body weight.

(Sitting position only)

Body Weight		Percentage of decrease of diastolic area and volume during systole.	
		Area	Volume
171.5 lbs.		14.35	20.71
169 "		13.60	19.72
	Avg.	13.975	20.215
165 "		13.61	16.79
163.5 "		11.15	16.39
	Avg.	12.38	18.09
155 "		9.91	14.46
152 "		9.5	14.1
	Avg.	9.705	14.28
148 "		9.55	14.01
146.3 "		13.53	20.85
	Avg.	11.54	17.43
145 "		20.62	29.30
143 "		11.32	16.75
141½ "		18.60	26.52
141 "		13.63	19.91
	Avg.	14.27	21.075
137.3 "		10.93	15.96
135		9.46	13.80

Weight		Area	Volume
155 pounds		11.53	16.75
134 "		15.07	21.86
	Av.	11.747	17.095
130 pounds		9.1	13.45
129 "		14.27	20.68
	Av.	11.685	17.035
115 pounds		10.81	15.80

The above data seems to show that there is very little correlation between the weight of an individual and the percentage of decrease of diastolic area and volume during systole.

A classification was next arranged according to height, based on a variation of not more than two inches.

Percentage of decrease of diastolic area and volume during systole in relation to body height.

(Sitting position only)

Height		Percentage of decrease of diastolic area and volume during systole	
		Area	Volume
72.5 inches		13.60	19.78
71.6 "		13.88	20.13
71.5 "		13.53	20.85
	Av.	13.705	20.49

Height		Percentage of decrease of diastolic area and volume during systole. Area	Volume
70½ inches		13.61	19.79
70 "		20.62	29.30
70 "		9.46	13.8
	Av.	14.56	20.96
69¾ inches		9.5	14.1
69¾ "		13.63	19.91
	Av.	11.565	17.00
69 inches		9.91	14.46
68.7 "		10.93	15.96
	Av.	10.42	15.21
68½ inches		8.13	12.05
68 "		14.35	20.71
68 "		15.07	21.86
67.5 "		18.60	26.52
	Av.	14.037	20.285
66 inches		11.53	16.75
66.5 "		7.30	10.56
	Av.	9.415	13.655
64.5 inches		14.27	20.64
64.5 "		9.1	13.43
	Av.	11.64	17.035
63		10.81	15.8

This table likewise shows no true correlation between the height of an individual and the percentage of decrease of diastolic area and volume during systole.

We may now consider the percentage of contraction in area and volume from the standpoing of bodily proportions. Fat individuals are classified according to the percentage of weight above normal for a given height. In order to get this data for the relative body proportions Dr. Bardeen's tables were again used. In this arrangement a variation of 5 points was allowed, that is from 1 to 5+ was normal and anything above or below that was either classified above or below normal. The data is as follows:

Percentage of contraction in area and volume
from the standpoint of bodily proportions.
(Sitting position)

Percentage of body weight normal for a given height			Percentage of decrease of diastolic area and volume during systole. Area	Volume
-16.4				
	-16.4		13.53	20.85
- 5	- 8.5		13.88	20.13
	-9.4		20.62	29.30
	-10.4		9.46	13.80
		Av.	14.65	21.076
-10				
	-1.7		13.60	19.72
	-2.9		15.07	21.86

Percentage of body weight normal for a given height			Percentage of decrease of diastolic area and volume during systole.	
			Area	Volume
-10	-3.5		10.81	15.80
	-5.3		10.93	15.96
	-6		13.63	19.91
		Av.	12.808	18.65
Normal 0 to 5+				
	+5		14.27	20.64
	+5		11.53	16.75
	+0.7		11.32	16.75
	+0.8		9.10	13.43
	+1.3		18.60	26.52
	+1.5		10.80	18.46
		Av.	12.60	18.758
5+ to 7				
	+6.2		9.91	14.46
+10	+8.6		13.61	19.79
	+8.0		9.55	14.01
		Av.	11.58	16.90
+10 to 17+			14.35	20.71

The above table does not show any correlation between the percentage of decrease of diastolic area and volume

during systole and the percentage of body weight for a given height.

The two following tables show the data for the percentage of contraction in volume from the standpoint of contraction in volume from the standpoint of the relative size of the heart in proportion to body weight. A variation of 3% was allowed.

Percentage of decrease of diastolic volume during systole to the relative size of the heart in proportion to body weight.

Relative size of the heart in proportion to body weight		Percentage of decrease of diastolic volume during systole. Volume
- 7.1		20.71
- 7.8		19.79
- 4.0		13.43
	Av.	17.97
- 1.4		20.13
- 2.9		14.46
- 3.0		16.75
- 3.0		16.91
- 3.5		20.85
	Av.	18.42

Relative size of the heart in proportion to body weight		Percentage of decrease of diastolic volume during systole. Volume
+ 2.3		26.52
+ 2.5		18.46
+ 2.9		29.30
	Avg.	24.76
+ 6.4		19.72
+ 6.4		20.64
+ 6.6		13.80
+ 8.8		15.80
	Avg.	17.69
+ 12.4		15.96
+ 14.2		16.75
	Avg.	15.545
+ 21.5		21.86
+ 27.5		14.01

Lying

- 1.4		16.39
- 2.9		14.46
- 3.0		12.05
	Avg.	14.30

Relative size of the heart in proportion to body weight		Percentage of decrease of diastolic volume during systole. Volume
+ 2.5		18.46
+ 6.6		14.38
	Avg.	16.42
+ 12.4		15.96
+ 14.2		16.93
	Avg.	16.495

Neither table shows any distinct correlation, the last table appears to show a correlation but it is so small and the data for the lying position is so limited that it can be overlooked.

A comparison based on the systolic pressure, pulse pressure and pulse rate was next worked out. In ease of all of these a variation of 4 points was allowed.

(Sitting position)

Systolic Pressure	Percentage of decrease of diastolic volume during systole	Pulse Pressure	Percentage of decrease of diastolic volume during systole
100	16.75	22	14.46
104	19.91	28	14.01
108	18.46	30	18.46
108	14.46	32	16.75
Av.	17.61		16.407

Systolic Pressure		Volume	Pulse Pressure	Volume
110		16.75	34	15.80
110		20.13	34	19.91
112		20.85	34	20.85
114		20.64	34	16.75
	Av.	19.59		18.43
116		15.80	36	20.64
120		13.43	36	13.43
116		13.80	36	19.72
118		21.86	36	26.52
			38	29.30
	Avg.	16.22		21.92
122		14.01	40	20.13
122		20.71	44	21.86
			44	20.71
	Avg.	17.36		20.90
128		19.72	48	19.79
130		19.79		
132		29.30		
134		26.52		
	Avg.	25.20		

Lying Position

104	12.05	36	16.93

Systolic Pressure		Volume	Pulse Pressure	Volume
		Lying Position (Cont'd)		
106		12.05	36	16.93
108		16.39	36	14.46
	Avg.	14.80		15.695
115		18.46	39	18.46
116		16.93	40	15.96
116		14.38	42	12.05
116		14.46	42	14.38
			43	16.39
	Avg.	16.056		15.448

Pulse Rate and Volume

(Sitting)			(Lying)		
Pulse Rate		Percentage of decrease of diastolic volume during systole	Pulse Rate		Percentage of decrease of diastolic volume during systole
64		20.13	52		16.39
67		15.80			
	Avg.	17.945	63		15.96
71		19.91	64		18.46
75		20.85		Avg.	17.21
75		20.64	68		14.46
73		14.46	70		16.93
	Avg.	18.965	72		14.38
				Avg.	15.256

(Sitting)			(Lying)	
Pulse Rate		Volume	Pulse Rate	Volume
78		16.75	81	12.05
82		14.01		
	Avg.	15.38		
84		20.71		
85		18.46		
86		19.72		
	Avg.	19.63		
88		21.86		
88		16.75		
88		29.30		
92		13.43		
	Avg.	20.335		
96		26.52		
100		19.79		
	Avg.	23.155		

There appears to be a rather distinct correlation between pulse pressure and percentage of decrease of systolic volume during systole, also a correlation with pulse rate, that is in the sitting position. As there tables show, however, the correlation is not perfect. In case of the lying position the limited amount of data accumulated is perhaps insufficient to draw conclusions, although the inference might be drawn that subjects with a

low systolic pressure have a smaller percentage of decrease of systolic volume during systole, than those with a higher systolic pressure. Pulse pressure, on the other hand is just opposite to this, that is, with a low pulse pressure we have a greater percentage of decrease of systolic volume during systole.

In calculating the percentage of blood output, we may assume the heart to be composed of 45% muscle and 55% of blood, at rest in inspiration in the sitting position (Bardeen). Thus, if the percentage of decrease in volume from systole to diastole is divided by 55 we obtain the percentage of blood output. The following is the result:

<u>Sitting</u>

1.	37.90%	10.	30.454%
2.	35.75%	11.	48.21%
3.	35.56%	12.	35.98%
4.	29.01%	13.	26.29%
5.	36.20%	14.	37.65%
6.	39.745%	15.	28.727%
7.	30.454%	16.	25.09%
8.	24.418%	17.	53.27%
9.	37.527%	18.	36.60%
		19.	25.47%

Avg. 34.60 - for 2 ventricles

Avg. 17.30 - for 1 ventricle

Lying

1. 33.56
2. 21.909
3. 30.78
4. 26.29
5. 26.145
6. 29.80
7. 19.20

Avg. 26.810 - for 2 ventricles

Avg. 13.405 - for 1 ventricle

The above data shows that the percentage of output in the sitting position is considerable more than in the lying position.

We may now consider the output in cubic centimeters per kilo of body weight per minute. We can arrive at this factor by finding the difference in volume of the heart during systole and diastole and dividing this number by two, so as to consider only one circulation. If this result is multiplied by the pulse rate, we obtain the number of c.c. per minute. It is necessary now, to divide this number by the number of kilos that the body weighs, the final result in c.c. per kilo of body weight per minute.

The following table shows the results obtained:

Sitting

1.	67.16 cc.	11.	140.07 cc.
2.	67.05 "	12.	67.57 "
3.	54.24 "	13.	122.59 "
4.	76.20 "	14.	118.48 "
5.	75.68 "	15.	68.81 "
6.	59.08 "	16.	63.05 "
7.	73.62 "	17.	86.85 "
8.	94.93 "	18.	73.27 "
9.	62.78 "	19.	96.73 "
10.	66.50 "		

Avg. 80.771 Cubic Centimeters

Lying

1. 47.89 cc.
2. 50.48 "
3. 50.529 "
4. 82.30 "
5. 49.41 "
6. 62.60 "
7. 54.90 "

Avg. 56.872 Cubic centimeters.

This data also shows that the output in the sitting position is much greater than that in the lying position. The actual results obtained will be discussed later.

A classification according to whether the heart was normal for a given weight, was made. A variation of 5 points was allowed.

Output in c.c. per kilo of body weight per minute. Classified according to weight i.e. heart normal for a given weight.

Percent	c.c.
- 16.4%	66.50 cc.
- 10.4%	59.08 cc.
- 9.9%	140.07 "
- 8.5%	67.16 "
- 6.0%	67.57 "
- 5.3%	68.81 "
	Avg. 80.538 c.c.
- 3.5%	62.78 cc.
- 2.9%	118.48 "
- 1.7%	94.93 "
	Avg. 92.06 cc.
Normal	
+ 1.5%	67.05 cc.
+ 1.3%	122.59 "
+ 1.0%	86.85 "
+ 1.0%	76.20 "
+ 0.7%	75.68 "
	Avg. 85.676 cc.
+ 6.2%	54.24 cc.
+ 8.0%	73.62 cc.
+ 8.0%	63.05 cc.
+ 8.6%	96.73 cc.
	Avg. 71.91 cc.

Percent	cc.
+ 17.4%	73.27

This table does not show anything of interest beside the fact that those subjects whose hearts are between - 5 and - 10 as to weight appear to have the same average as obtained in the grand average for the sitting position. It is impossible to tell whether this is a true correlation or not.

The last classification is that which is arranged according to height. A variation of 2 inches being allowed.

Output in c.c. per kilo of body weight per minute.

Arranged according to height.

Inches		Cubic centimeters
72.5 inches		94.93 cc.
71.6 "		62.78 "
71.25 "		66.50 "
70.25 "		96.73 "
70.00 "		59.08 "
70.00 "		140.07 "
	Avg.	76,681 cc.
69.75 "		67.05 "
69.75 "		67.57 "
69.00 "		54.24 "
	Avg.	62.953 cc.

Inches		Cubic Centimeters
68.70		68.81 cc.
68.25		75.68 "
68.00		118.45 "
68.00		73.27 "
67.50		122.59 "
66.50		73.62 "
66.00		76.20 "
	Avg.	86.945 "
64.50		86.85 "
64.50		63.05 "
63.00		62.78 "
	Avg.	70.89 "

The above results show that tall individuals and those of normal height (68 inches) seem to have the most normal output, that is, by taking the grand average as a standard in the sitting position. Short individuals have, seemingly a smaller output than those of medium height or tall individuals.

To summarise, it can be said that a true correlation appears to exist between systolic pressure and percentage of decrease of diastolic volume during systole; this is also true of pulse rate. Also, that in the lying position the heart has a much smaller output than in the sitting position. Another important correlation is that a large

heart shows a smaller change in volume.

As to the actual output of the heart, the average for the sitting position as previously mentioned, was 80.77 cc., while that in the lying position was considerably less, 56.87 cc. per kilo of body weight per minute. These results compare to those obtained by other workers as follows:

Passawart 42.75 cc. per beat

Tigerstedt 50 - 100 cc. per beat

Martin 180 cc. per beat

Stewart 102.08 cc. per beat

Vierordt 180 cc. per beat

Lindhardt 72 cc. per beat

Krogh and Lindhardt 40 cc - 308.57 cc. per beat.

The results obtained by Krogh and Lindhardt show such a wide variation, that the actual results mean but very little except that there is a wide difference in cardiac output when the body is at rest and when in active exercise.

In conclusion, therefore, the wide variation as shown by the above figures do not give us any authentic results. The only way to obtain a standard for a working basis, is to find out first, whether or not a heart is normal for a subject's given height and weight, knowing this and then ascertaining its actual output, a result would be obtained which would really stand for something. The difficulty of attacking the problem of actual output in man, however, it seems is almost insurmountable as indirect methods have to be employed. In the case of lower animals it is some-

what easier, but there the question arises as to residual blood in the heart after systole, the question of nerve mechanism, the unnatural condition of the animal while the experiment is carried on, the influence of the anaesthetic, and in fact many details which at first sight appear to be trivial, but when looked at from a scientific standpoint, appear as a great obstacle to anything like obtaining standard results. The method as outlined in this paper has perhaps surmounted a few of the difficulties and eliminated some of the obstacles. Let it be understood, however, that it is open to criticism and is subject to a greater or less percentage of error, but at the present time it is perhaps the most direct method which has as yet been employed on man. The problem still remains open to investigation and it is to be hoped that before long a satisfactory method may be developed which will practically eliminate the possibility of error and which will truly solve the problem of cardiac output.

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